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ON SURFACE ELECTROMAGNETIC WAVES IN SYSTEMS WITH NONUNIFORM IMPEDANCE

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is known, nonuniformities in the surface impedance [1] in unshielded retarding systems generally lead to the transformation of the surface wave energy into radiation field energy [2]. Moreover, there are cases when the system with a nonuniform impedance permits the existence of surface waves, which are analogous to surface waves in systems with uniform impedance with respect to both the field configuration and in that they are normal waves orthogonal to fields of other types.

As an example, let us analyze two-dimensional waves with the component $H_z \neq 0$ (r, φ, z are cylindrical coordinates) within the two-sided angle ($\varphi = 0$, $\varphi = \varphi_0$, $0 < \varphi_0 \leq 2\pi$) on the faces of which are prescribed the homogeneous boundary conditions

$$E_r = Z^{(1)}(r)H_z\big|_{\varphi=0} ; \qquad E_r = - Z^{(2)}(r)H_z\big|_{\varphi=\varphi_0}$$

Let the surface impedances $Z^{(1)}$, $Z^{(2)}$ depend on the r coordinate as $\frac{1}{r}$:

$$Z^{(1)} = i\frac{q_1}{kr}Z_0 ; \qquad Z^{(2)} = i\frac{q_2}{kr}Z_0 \qquad (\mathrm{Im}\, q_1 = \mathrm{Im}\, q_2 = 0)-$$

($k = \omega\sqrt{\mu\varepsilon}$; $Z_0 = \sqrt{\frac{\mu}{\varepsilon}}$; μ, ε are the parameters of the homogeneous medium filling the space between the faces). The following functions will be solutions of the wave equation for H_z

$$H_{z_m} = H^{(1,2)}_{\nu_m}(kr)\left[q_1 \sin \nu_m\varphi - \nu_m \cos \nu_m\varphi\right] \tag{1}$$

where $H^{(1,2)}_{\nu_m}(kr)$ is the Hankel function of order ν_m of the first and second kind and ν_m are the roots of the characteristic equation

$$(q_1q_2 - \nu_m^2)\tan \nu_m\varphi_0 = \nu_m(q_1 + q_2) \tag{2}$$

In addition to an infinite number of real roots, equation (2) has either one or two pure imaginary roots $\nu_k = i\nu_k$ for definite values of the parameters q_1, q_2 and the angle φ_0, which correspond to waves similar to slow waves between two parallel impedance planes.

In the particular case when $q_1 = - q_2 = q > 0$, along with the eigenfunctions (1) for $\nu_m = \frac{m\pi}{\varphi_0}$ ($m = 1,2,3,\ldots$), the following functions will also

be solutions

(3) $$H_{z_0} = H^{(1,2)}_{iq}(kr)\, e^{-q\varphi}$$

These functions describe a field decreasing exponentially in azimuth φ and independent of the angle φ_0. The latter can be taken equal to π, say, which corresponds to the two-sided angle becoming a plane. It is not difficult to show that the functions $H_{z_m}(r,\varphi)$ $(m = 1,2,..)$ and $H_{z_0}(r,\varphi)$ form an orthogonal system in the interval $(0 \leq \varphi \leq \varphi_0)$.

Under the condition that $\exp(-q\varphi_0) \ll 1$, the face $\varphi = \varphi_0$ plays almost no part in the formation of the wave (3). Hence, we arrive at a surface wave with a cylindrical front which is propagated along a plane with a nonuniform impedance.

Substituting the asymptotic expressions [3] in (3) for the Hankel functions with large arguments $kr \gtrsim q$, we obtain the eigenfunctions

(4) $$H_{z_0} \sim \sqrt{\frac{2Q(r)}{\pi q}\sqrt{1 + Q^2(r)}}\, \exp\left[\mp i \int k\sqrt{1 + Q^2(r)}\, dr - q\varphi + C\right]$$

which describe surface waves with slowly varying amplitude and phase rate. C is a constant and $Q(r) = \frac{q}{kr}$ in (4).

The system considered is the simplest model of a nonuniform, retarding structure which permits the picture of wave propagation to be described sufficiently graphically. Moreover, it is of known interest from the viewpoint of certain applications also. Thus, for example, the use in plane antennas of surface waves of retarding systems with a surface impedance varying as $\frac{1}{r}$, affords the possibility not only of obtaining the required dimensions of the effective antenna aperture but also (which is no less important) of making a computation of the antenna just as in the computation of horn emitters.

The method used above of separating variables in curvilinear coordinates (cylindrical in this case) can be used to solve problems of wave propagation for certain other dependences of the surface impedance on the coordinate, which are related in a definite way to the Lame parameters for the appropriate coordinate system. It should here be kept in mind that nonuniform waves, localized to some degree or other at the impedance surfaces, cannot in the general case also have the character of surface fields such as (3) which decrease monotonically and rapidly enough (purely exponentially, say) upon removal from the

surface in the direction of the change of the appropriate curvilinear coordinate.

Radio Physics Research Inst. of Gor'kii Univ. Dec. 17, 1958

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